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COLOR TRANSPARENCY EFFECTS FROM MOSAICS OF OPAQUE COLOR.(U)
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COLOR TRANSPARENCY EFFECTS FROM MOSAICS OF OPAQUE COLOR

PART I, Underlying colorimetric principles

PART II, An implementation on a computer-driven color raster-scan display.

FINAL REPORT

Richard A. Bolt

Nicholas Negroponte

Victor Tom

June 1977

Prepared for

U. S. ARMY RESEARCH OFFICE

Contract No. DAAG29-76-C-0037

Contract period: 15 June 1976 - 14 June 1977

Prepared by

Architecture Machine Group

Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Final Report	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 COLOR TRANSPARENCY EFFECTS FROM MOSAICS OF OPAQUE COLOR.		5. TYPE OF REPORT & PERIOD COVERED Final Report, 15 June 76 - 14 Jun 77,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Richard A. Bolt Nicholas Negroponte Victor Tom		8. CONTRACT OR GRANT NUMBER(s) 15 DAAG29-76-C-0037 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS Architecture Machine Group 410308 Massachusetts Institute of Technology Cambridge, Massachusetts 02139 New		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project No. 17 16 1T161102BH57-03
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office Post Office Box 12211 Research Triangle Park, NC 27709		12. REPORT DATE 11 June 1977
		13. NUMBER OF PAGES 41
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 46p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

18 ARO

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA 19 14157.1-EL

18. SUPPLEMENTARY NOTES

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Color	Computers
Transparency	Computer display
Color display	Raster-scan display
Color coding	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Principles of "color scission", first demonstrated by Heider in 1933, have been stated by Metelli (1970;1974) for achromatic color. Such principles, together with certain figural constraints, can form the basis of perceptual transparency effects arising from mosaics of opaque color. The work described extends Metelli's lead into full chromatic color space. An illustrative example is given of how dynamic transparency effects have been implemented on a computer-driven raster-scan display. The potential utility of

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COLOR TRANSPARENCY EFFECTS
FROM MOSAICS OF OPAQUE COLOR

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Abstract

Principles of "color scission", first demonstrated by Heider in 1933, ~~have been~~ were stated by Metelli (1970, 1974) for achromatic color. Such principles, together with certain figural constraints, can form the basis of perceptual transparency effects arising from mosaics of opaque color. The work described extends Metelli's lead into full chromatic color space. An illustrative application is given of how dynamic transparency effects ~~have been~~ were implemented on a computer-driven color raster-scan display. The potential utility of such displays is discussed.

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PART I:

Underlying colorimetric principles

Introduction

The perception of transparency arises when we not only see surfaces and objects which are behind others, but when we are perceptually aware of the transparent medium or object itself. Specifically, we regard some surface as transparent when we _see through_ it to other surfaces while at the same time being aware that it is nonetheless there. A perfectly clear plate-glass window with no reflection is not "transparent", then, according to this definition. We see through it, to be sure, but we don't see it as being there. If, however, there are marks or reflections on the glass, then we perceive that we are looking through the glass. This specific visual awareness that we are _looking through_ some medium is what is meant by the perception of transparency.

The perception of transparency, however, need not necessarily depend upon actual _physical_ transparency such as that of a pane of glass. Work by Fabio Metelli (Metelli, 1970;1974) demonstrates how mosaic patterns of opaque colors may take on the appearance of transparent layers of color overlaying other layers of color. The emergence of such color transparency effects from mosaics of opaque colors rests upon two sets of conditions being met: 1) conditions having to do with the _configuration_ of the mosaic; and, 2) conditions having to do with the _color relationships_ between the parts of the mosaic.

Necessary figural conditions for effects of trans-

parency are listed by Metelli, and include: figural unity of the transparent layer; continuity of the boundary line; adequate stratification. A comprehensive account of these conditions is given in Metelli (1970; 1974) and they will be recapitulated only briefly here.

To paraphrase Metelli, the condition of figural unity is met when the unity of the central region of a transparent shape is not broken up figurally. The condition of continuity of the boundary line means that the boundary which divides a figure into two regions, one dark and one light, must appear to belong to the opaque regions behind the transparent layer. Especially destructive of the impression of transparency is a break in the continuity of the boundary line where it intersects the transparent layer. Lastly, because the effect of transparency means seeing surfaces behind a transparent medium or object, the color layer to be seen as transparent must appear to be located on or above the surface of the opaque object. In order to create such adequate stratification for transparency, the underlying opaque regions must appear to meet under the whole of the transparent layer.

These figural conditions are necessary conditions, but are not sufficient conditions for the perception of transparency. That is, these conditions must be met for the impression of transparency to arise, but the meeting of them will not of itself guarantee that a strong impression of transparency will be created.

The above figural requirements having been met, the

remaining general requirement is that the color relationships of the parts of the mosaic bear certain relationsnips to each other. In particular, a perceptual effect termed "color scission", first formally demonstrated by Grace Moore Heider of Smith College in 1933 (Cf. Metelli, 1974, p. 93), is essential to the perception of transparency.

Color scission

Consider an example from Metelli of a transparent strip "T" overlaying a two-color background of colors "A_1" and "A_2". The shapes depicted in Figure 1 for this example meet all of the configurational requirements mentioned above.

The effect of transparency, according to Metelli, arises from a perceptual splitting or "color scission" of the colors A_1' and A_2', that is of the two pieces of the mosaic which together make up the strip T which is to be perceived as being transparent. This splitting or "scission" is depicted in Figure 2.

Metelli gives relational formulae as to what the color relationships should be when good transparency effects occur: e.g., $A_1 > A_1' > T$, where " >" means "lighter than," or "having more luminance than." However, Metelli furnishes these relationships for achromatic color only, citing the complexity of measuring chromatic color (Cf. Metelli, 1974, p. 93). Achromatic color (white, gray, black) of course varies in one dimension only, namely brightness.

The current work extends the formulae underlying

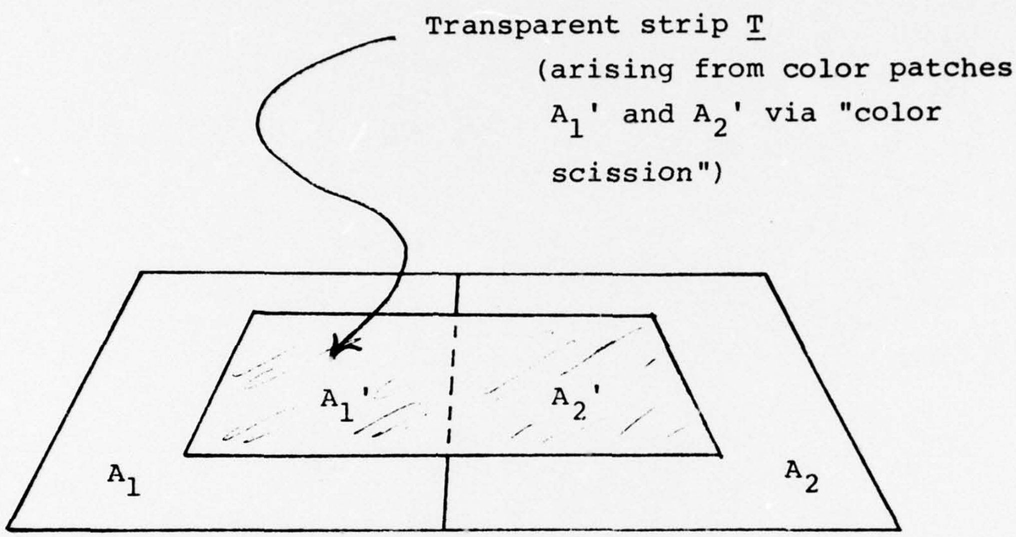


Figure 1

Basic figure showing color patches
involved in "color scission"

(Figure adapted from Metelli, 1974)

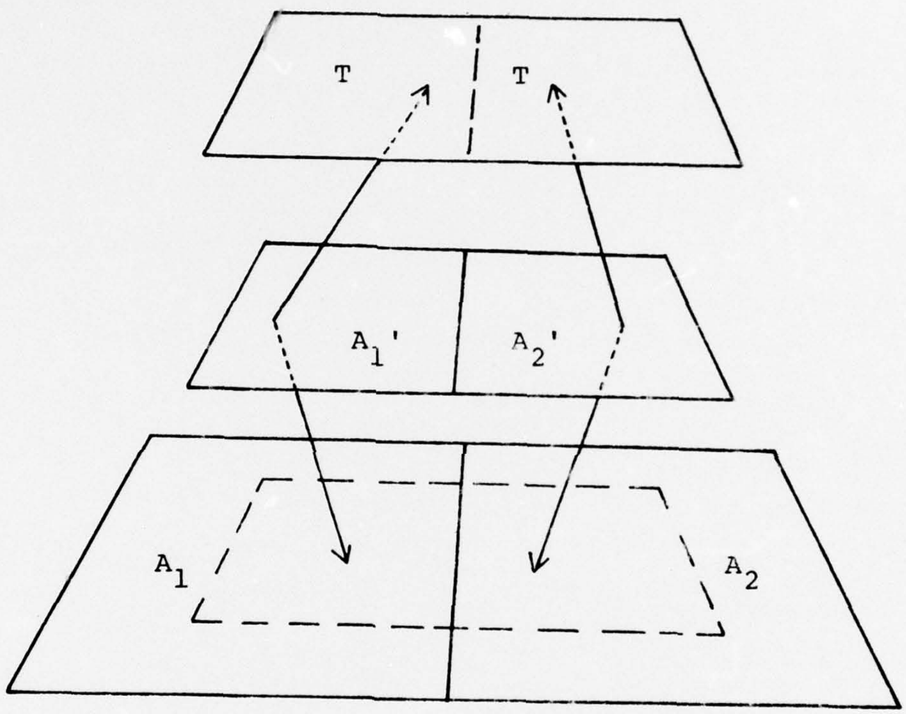


Figure 2

Color scission: colors A_1' and A_2' are perceptually split (undergo "scission") into components T, which "go to " the transparent strip overlaying the base figure, and into colors A_1 and A_2 which "go to" the bipartite color field of the base.

color scission to full chromatic color space. However, before we extend the interpretation and algebraic formulae for transparency to the full color realm, let us review some basic colorimetry.

Colorimetry

All systems of tristimulus colorimetry are based on two premises: 1) color is a three-dimensional property of light, and 2) the amounts of three color primaries to match an unknown color may be used as numerical dimensions to specify the color. (Cf. Cornsweet, 1965; Wyszecki and Stiles, 1967.) For example, pertaining to our own raster-scan display system, colors are generated by modulating the light emittances from red, green, and blue phosphors. The unique specification of a color is given by:

$$\text{color } C = r_c \cdot R + g_c \cdot G + b_c \cdot B \tag{1}$$

where r_c, g_c, and b_c are integral and range from 0 to 31 inclusive. A human observer, however, does not readily perceive absolute amounts of red, green, and blue in a color, but more likely its brightness and chroma (hue, saturation). We are motivated towards projecting the RGB space into a luminance dimension and a chrominance plane.

Luminance refers to that characteristic of light which elicits the sensation of brightness. The relation between luminance and primary values is governed by the

phosphor characteristics, and in our case by

$$L_c = .30r_c + .59g_c + .11b_c \qquad (2)$$

where r_c, g_c, and b_c are defined as in Equation (1). (Cf. Wentworth, 1955.) In addition, the luminance resulting from the mixture of several colors is the sum of the luminances of each of them (per Grassman's Laws; cf. Graham, 1965, p. 372). Color additively projected onto the luminance dimension exhibits linear properties.

The standard CIE chromaticity diagram is chosen on which to project the chroma of a color. In order to use this representation, all colors must be specified in terms of a set of standardized "imaginary" primaries, tristimulus values. A color stimulus, defined physically by its spectral-power distribution, $f(\lambda)$, can be reduced to the tristimulus set by

$$\begin{aligned} X &= \kappa \int_{380}^{770} f(\lambda)\bar{x}(\lambda)\Delta\lambda \\ Y &= \kappa \int_{380}^{770} f(\lambda)\bar{y}(\lambda)\Delta\lambda \qquad (3) \\ Z &= \kappa \int_{380}^{770} f(\lambda)\bar{z}(\lambda)\Delta\lambda \end{aligned}$$

where $\bar{x}$, $\bar{y}$, and $\bar{z}$ are the color matching functions, and $\bar{y}$

is also referred to as the luminosity function. κ is a normalizing constant dependant on the units in the expression. The chromaticity values for color C are defined as relative proportions of the tristimulus values

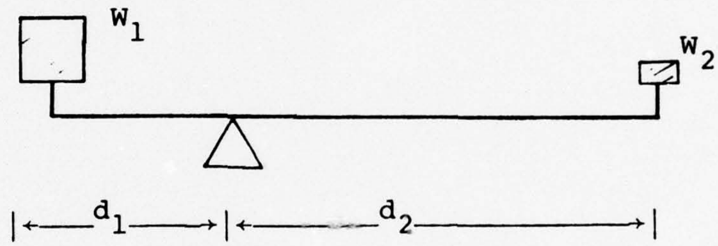
$$x_C = \frac{X_C}{X_C + Y_C + Z_C}, \quad y_C = \frac{Y_C}{X_C + Y_C + Z_C},$$

$$x_C + y_C + z_C = 1, \tag{4}$$

and the luminance can also be given in terms of tristimulus values,

$$L_C = Y_C \tag{5}$$

The notion of a color's "weight" is introduced here in order to clarify color mixtures in the CIE diagram. From Grassman's Law, the chromaticity mixture (C') of the two colors (C_1, C_2), will lie somewhere on the line segment determined by C_1 and C_2. The exact location of C' is calculated by utilizing a center-of-gravity principle from physical laws. If two weights are balanced on the ends of a weightless bar, the distances between the weights and the fulcrum are inversely related to the relative weights (see Figure 3). C' would therefore be located at



When balanced,

$$\frac{d_1}{d_2} = \frac{W_2}{W_1}$$

Figure 3

"Center-of-gravity" principle

the balance point determined by the color "weights" of C_1 and C_2. These "weights" must be proportional to the sum of the tristimulus values $(X_i + Y_i + Z_i)$. Expressing this value in terms of luminances and chrominances (L, x, y), we have

$$X_c + Y_c + Z_c = \frac{Y_c}{y_c} = \frac{L_c}{y_c}, \tag{6}$$

the exact specificity for a color mixture C' of C_1 and C_2 by using the geometries of Figure 3, and the linear properties of luminance.

$$L_{c'} = L_{c_1} + L_{c_2} \tag{7}$$

$$x_{c'} = \frac{w_{c_1}}{w_{c_1} + w_{c_2}} \cdot x_{c_1} + \frac{w_{c_2}}{w_{c_1} + w_{c_2}} \cdot x_{c_2}$$

$$y_{c'} = \frac{w_{c_1}}{w_{c_1} + w_{c_2}} \cdot y_{c_1} + \frac{w_{c_2}}{w_{c_1} + w_{c_2}} \cdot y_{c_2}$$

where $w_{c_1} = \dfrac{L_{c_1}}{y_{c_1}}, \quad w_{c_2} = \dfrac{L_{c_2}}{y_{c_2}}$

The chromaticity mixture is recognized as a weighted average of the component chromaticities.

We are now in a position to state the formulae for the construction of transparency on two projections, one onto luminance and the other onto chrominance.

Color Transparency Construction

Restating Metelli's formula for a transparent layer, T, overlaying a background color, A:

$$A' = \alpha A + (1-\alpha)T \qquad 0 \leq \alpha \leq 1 \tag{8}$$

where A' is the perceived color of the background A as seen through a transparent layer of color T. Alpha represents the transparent coefficient, the value of unity corresponding to total transparent and zero to total opaqueness. The color A' arises from the color mixing of A and T in the proportions α and $(1-\alpha)$ respectively. Incorporating this alpha constant into equations (7), we get

$$L_{A'} = \alpha L_A + (1-\alpha) L_T \ ,$$

$$x_{A'} = \frac{\alpha W_A}{\alpha W_A + (1-\alpha) W_T} \cdot x_A + \frac{(1-\alpha) W_T}{\alpha W_A + (1-\alpha) W_T} \cdot x_T \ , \tag{9}$$

and

$$y_{A'} = \frac{\alpha W_A}{\alpha W_A + (1-\alpha)W_T} \cdot y_A + \frac{(1-\alpha)W_T}{\alpha W_A + (1-\alpha)W_T} \cdot y_T .$$

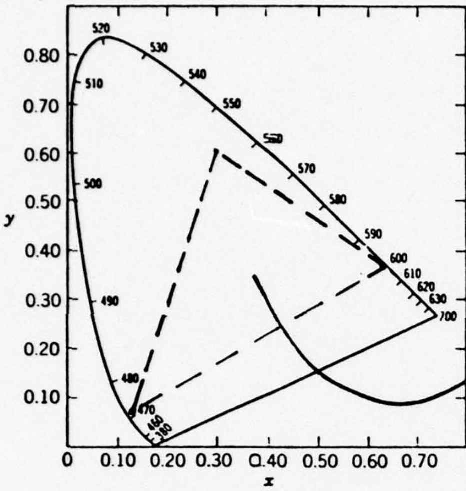
We note that in the special case when $W_A = W_T$, i.e., when the color "weights" are equal, equations (9) reduce to

$$\begin{pmatrix} L_{A'} \\ x_{A'} \\ y_{A'} \end{pmatrix} = \alpha \begin{pmatrix} L_A \\ x_A \\ y_A \end{pmatrix} + (1-\alpha) \begin{pmatrix} L_T \\ x_T \\ y_T \end{pmatrix} \qquad (10)$$

One can approximate the chromaticity of A' ($x_{A'}$, $y_{A'}$) by using equation (9) and then shifting ($x_{A'}$, $y_{A'}$) towards A or T depending on the relative values of W_A and W_T. In Figure 4 some examples are plotted for varying W_A and W_T.

Color Scission on Two Projections

Having developed algebraic formulae for color transparency construction, we now relate these formulae to the perceptual effect of "color scission".

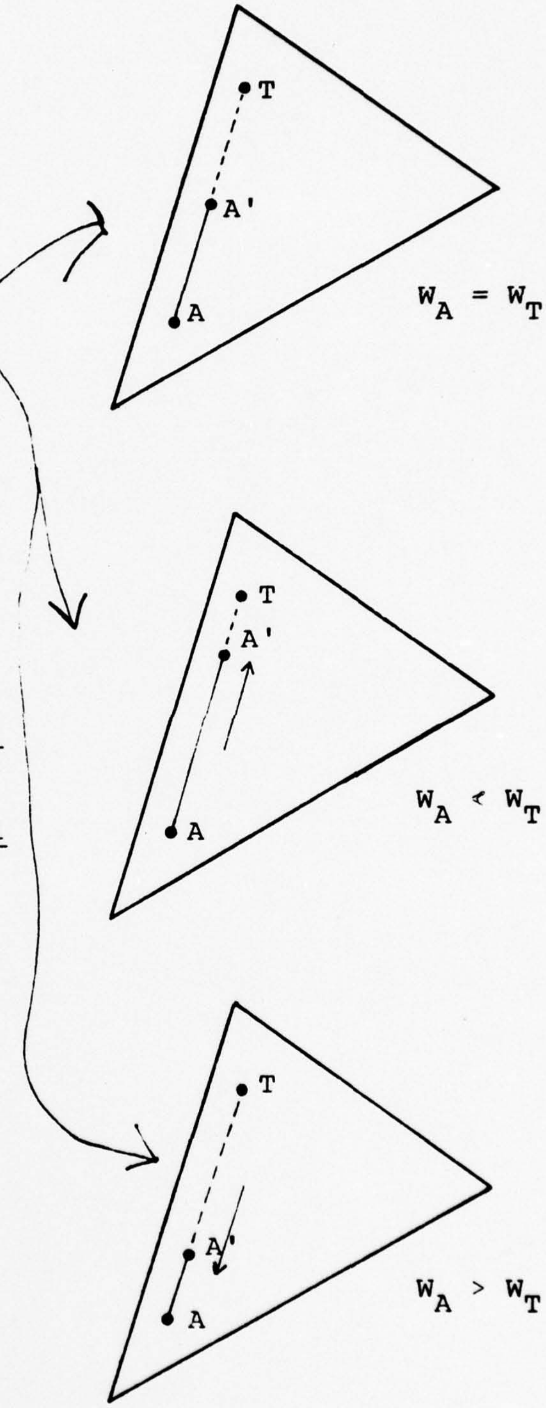


The CIE Chromaticity
Diagram

- At the right is that subspace of the CIE space which represents the color gamut of Tektronix 650-1 color monitor in our display system. <u>This CIE subspace will appear in later Figures of this report</u>.

Figure 4

Varying W_A and W_T



The theory of color scission from Metelli explains color transparency as a case of perceptual color-splitting. We choose to interpret the scission on two projections, luminance and chrominance. Assuming, as does Metelli, that color scission acts in a manner opposite to the law of color fusion (Talbot's Law), then the proportions of the stimulus luminance and chrominance that are perceived as the virtual color or as the background color are governed by the previously dervived formulae for the construction of transparency.

Metelli describes the necessary luminance conditions for perceptual transparency in his exposition of the achromatic case. We restate his result for the two-background-color situation. From the luminance formulas (9,10) certain perceived brightness relations must be satisfied:

$$A_1 > A_1' > T \quad \text{and} \quad A_2 > A_2' > T$$

or

$$A_1 > A_1' > T \quad \text{and} \quad T > A_2' > A_2$$

or

$$T > A_1' > A_1 \quad \text{and} \quad T > A_2' > A_2$$

or

$$T > A_1' > A_1 \quad \text{and} \quad A_2 > A_2' > T$$

(where the symbol "> " means "lighter than")

In addition, since the luminance formulation is linear, then the brightness ordering of the background predetermines the brightness ordering of the primed (') values:

$$\text{if } A_1 > A_2 > \ldots > A_j > T, \text{ then } A_1' > A_2' > \ldots > A_j'$$

$$\text{if } T > A_1 > A_2 > \ldots > A_j, \text{ then } A_1' > A_2' > \ldots > A_j'$$

In the full color realm, we can also consider color transparency effects on a constant luminance plane, manipulating only chrominance values. In this case,

$$A_1 = A_1' = A_2 = A_2' \ldots A_j = A_j' = T$$

Under conditions of constant luminance for the constituents of the mosaic, the appearance was, from our observations, that of a "smokey glass" or "milkly glass" effect, rather than one of transparency proper. Apparently, a differential luminance is necessary for transparency, and differences in chrominance only may underlie a color scission which corresponds to some sort of splitting into surfaces which are perceived as somehow separate, yet not as being one transparent surface over another surface. (See also the section, "Special Cases", below.)

Let us now define a chrominance scission as projected onto a CIE coordinate system, specifically that subset of CIE diagram space determined by our systems's CRT phosphors. Again, we refer to the basic mosaic pattern depicted in Figure 1. The four color components of the mosaic (A_1, A_1', A_2, A_2') are plotted on a CIE diagram in Figure 5. We postulate that if transparency is perceived, a chrominance scission has occurred and A_1' is perceptually split into two colors, A_1, which is a given background color, and T_1, which will have its locus somewhere along the projection $\overrightarrow{A_1 - A_1'}$. Similarly, A_2' splits into A_2, and into some color T_2 which lies along the projection $\overrightarrow{A_2 - A_2'}$. Therefore, if

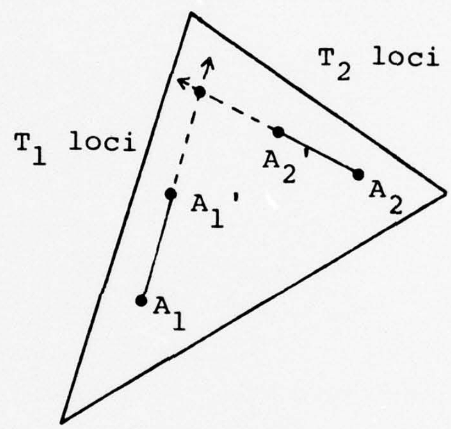


Figure 5

Intersecting loci of virtual T. The perceived color T should be at the intersection of the A_i to A_i' projections.

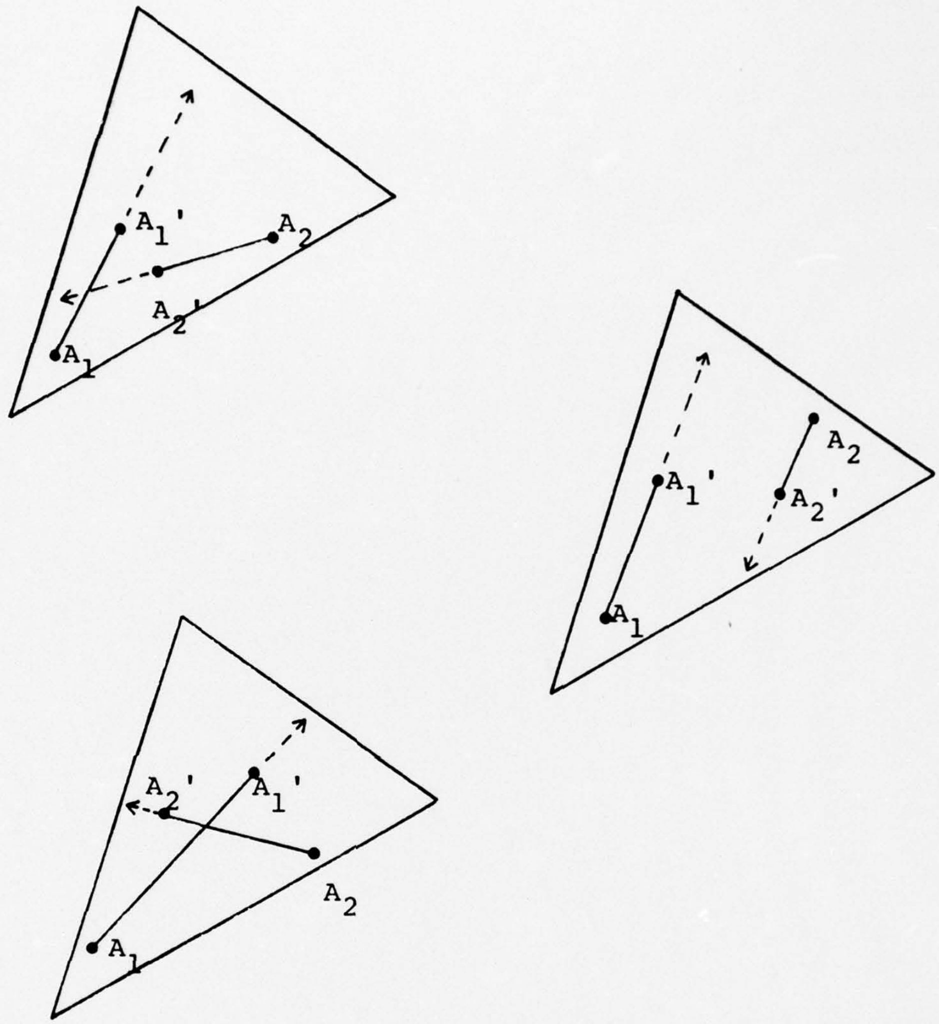


Figure 6

Null set intersections for the A_i to A_i' projections

niform color transparency is perceived, the virtual or T will be at the intersection of the projections, re $T_1 = T_2$. (See Figure 5.)

If the intersection of T_1 and T_2 is the null set, n the perception of a uniform color transparency will impossible. Such instances are shown in Figure 6. Accordly, where a transparent layer of uniform appearance (and, ice, of convincing transparency) is desired, T is first ermined, and the loci of the A_i' values are then deterled by the locus of T taken together with the loci of the e color values.

mples of Color Scission

The color undergoing scission exhibits an index transparency that is related to its position on the omaticity diagram relative to the base colors and a tual transparency color. In a similar fashion, the ghtness value also influences the apparent transparency. is obvious that the closer the composite colors are to base (or virtual) colors, the more transparent (or ique) the layer appears. Color Plates I through IV ustrate the basic mosaic pattern and the effects of nging various chromaticities on the perceived transency.

In Plate I-a, we have a yellow virtual placed over yan and magenta bi-partite field, shown with its ompanying chromaticity diagram (Plate I-b). The alpha .3, corresponding to "somewhat transparent". In Plates

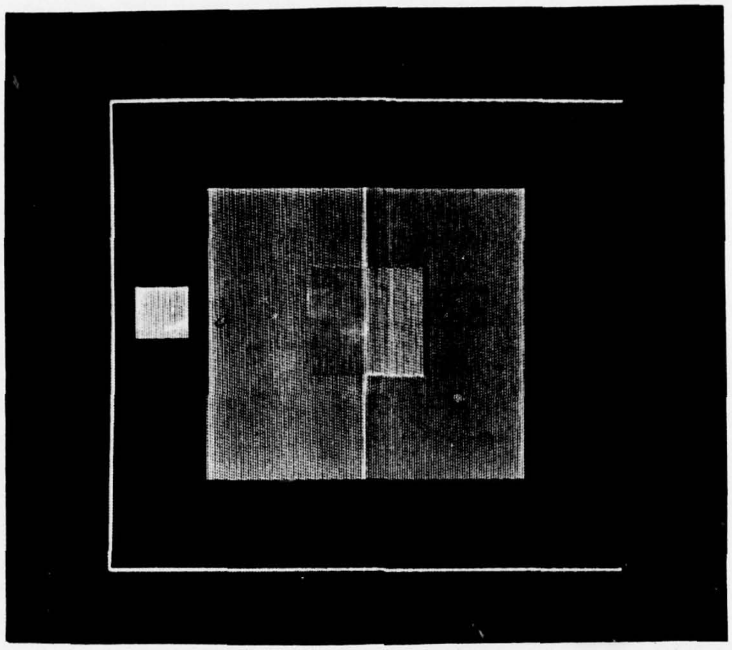


PLATE I-a.

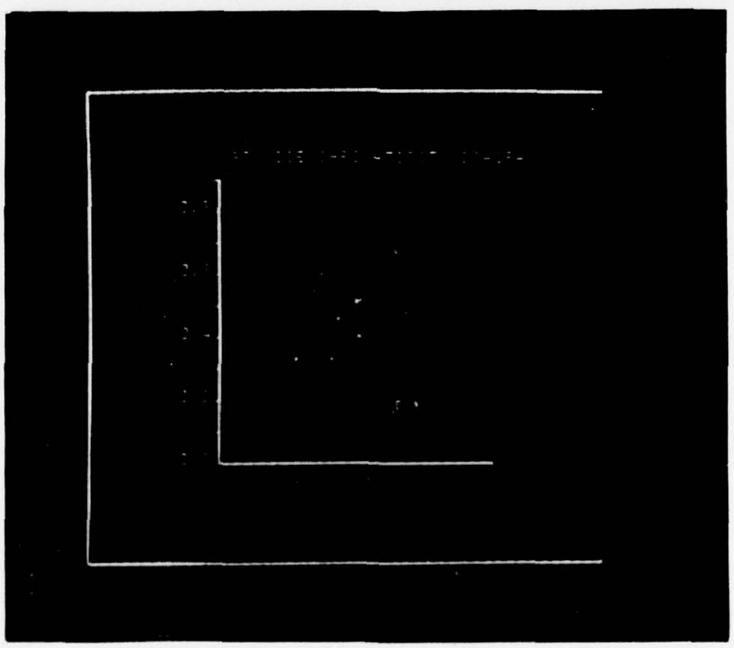


PLATE I-b.

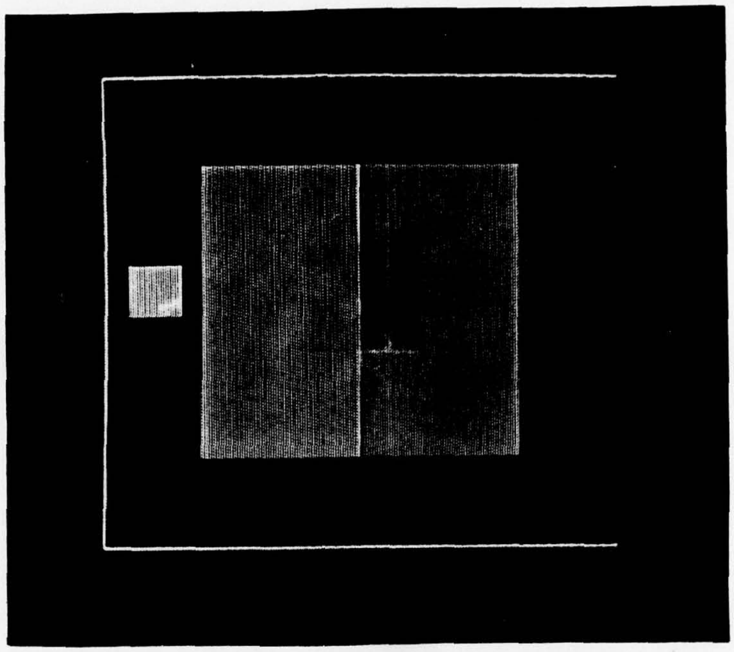


PLATE II-a.

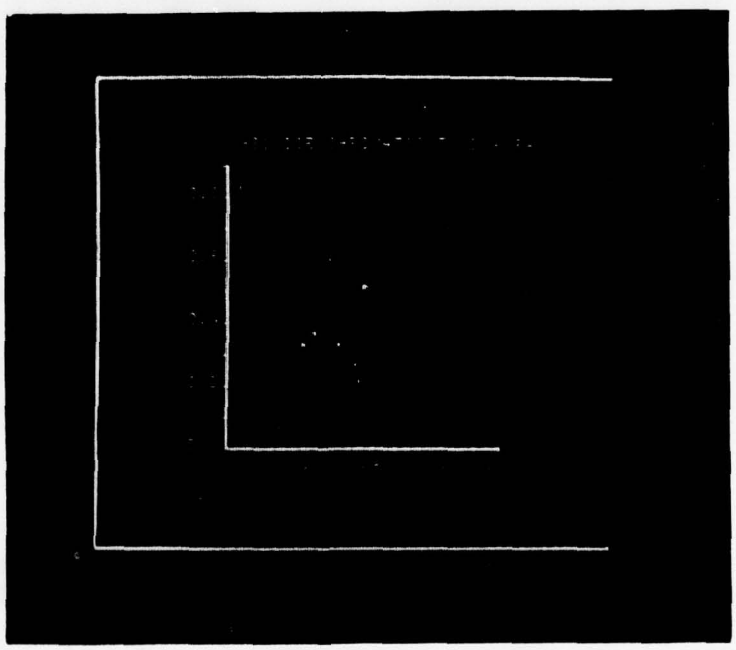


PLATE II-b.

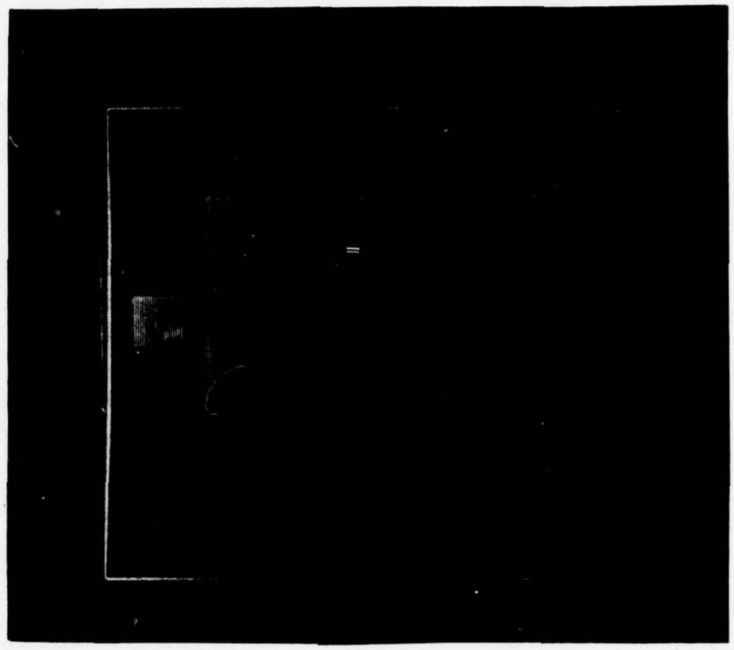


PLATE III-a.

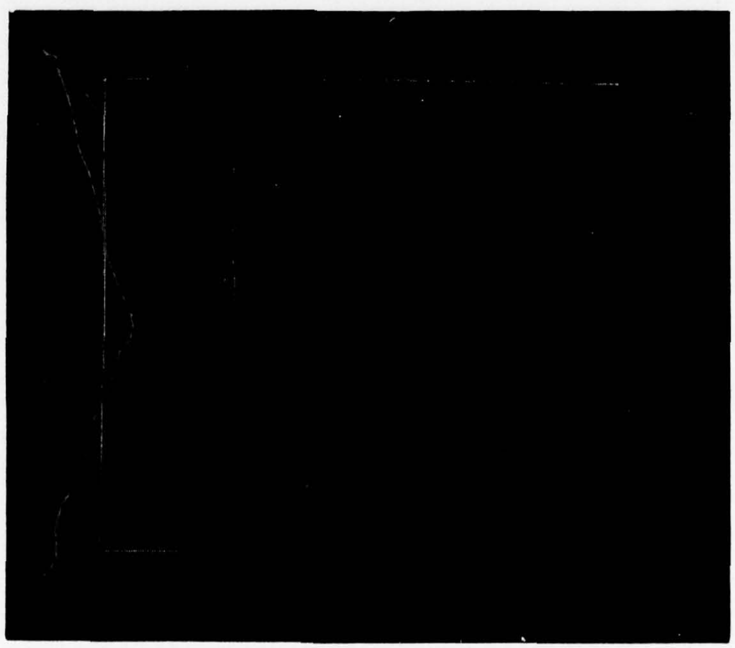


PLATE III-b.

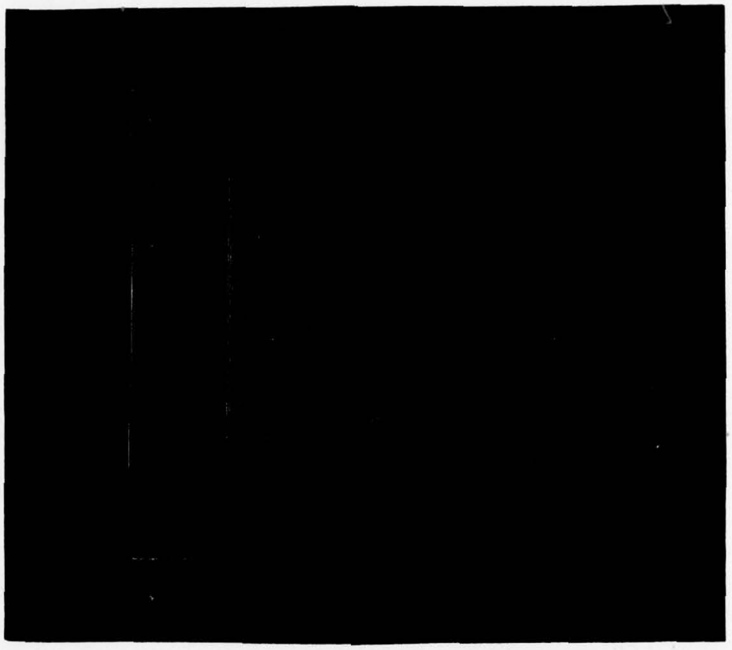


PLATE IV-a.

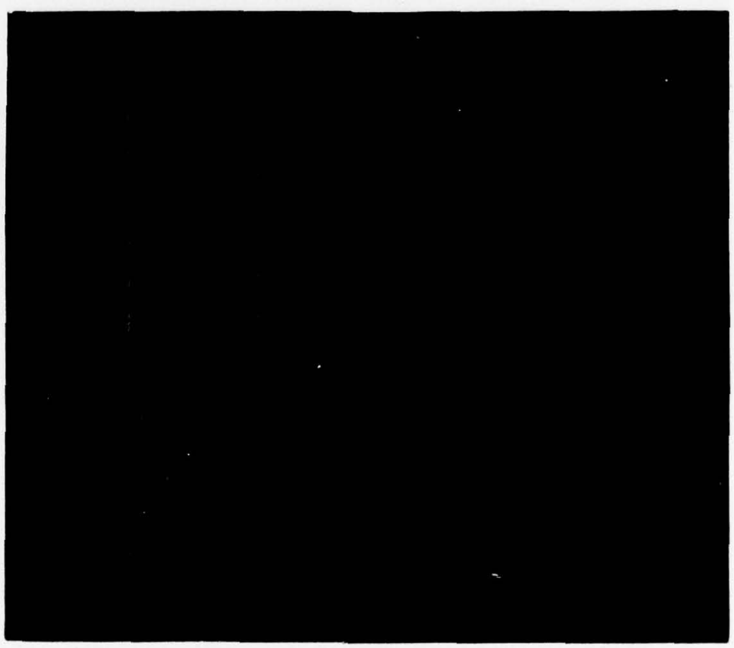


PLATE IV-b.

II-a and II-b, the composite colors A_1' and A_2' were shifted towards the base colors, theoretically conveying an alpha of .7, or "highly transparent". The brightness values were also appropriately adjusted. Returning to an alpha of .3, we then change the chromas of A_1' and A_2' such that they project onto a new virtual color T, an orange color, as depicted in Plate III-a,b. Finally, in Plates IV-a,b the base color A_1 and the composite color A_1' are altered so that A_1 is yellow, but that they still maintain their projection on the orange T.

(Note: All of the color Plates were photographed as Ektachrome transparencies directly from the face of the Tektronix 650 monitor on our computer system. In turn, the transparencies were printed on a Xerox 6500 Color Copier. These intervening steps inevitably introduce some distortion into the Plates, making them less satisfactory of course than viewing the display directly. This is especially true in that, on the computer system, the transparent color patch (or, in Plates V and VI, patch<u>es</u>) can be made to move about, as well as dynamically change its alpha (index of transparency). Nonetheless, the Plates convey a fairly good impression of the transparency examples.)

The considerations of multiple background colors involve no further complexities. For each background color A_i,(i= 1,2 ... n) there must be a composite color A_i' which scissions (will undergo scission) into A_i and a virtual color T. Therefore all the line segments $\overrightarrow{A_i - A_i'}$ project onto point T in the chromaticity plane. Using the techniques of transparency construction, we can easily compute all the A_i' for A_i and T within the allowable chromatic gamut. Figure 7

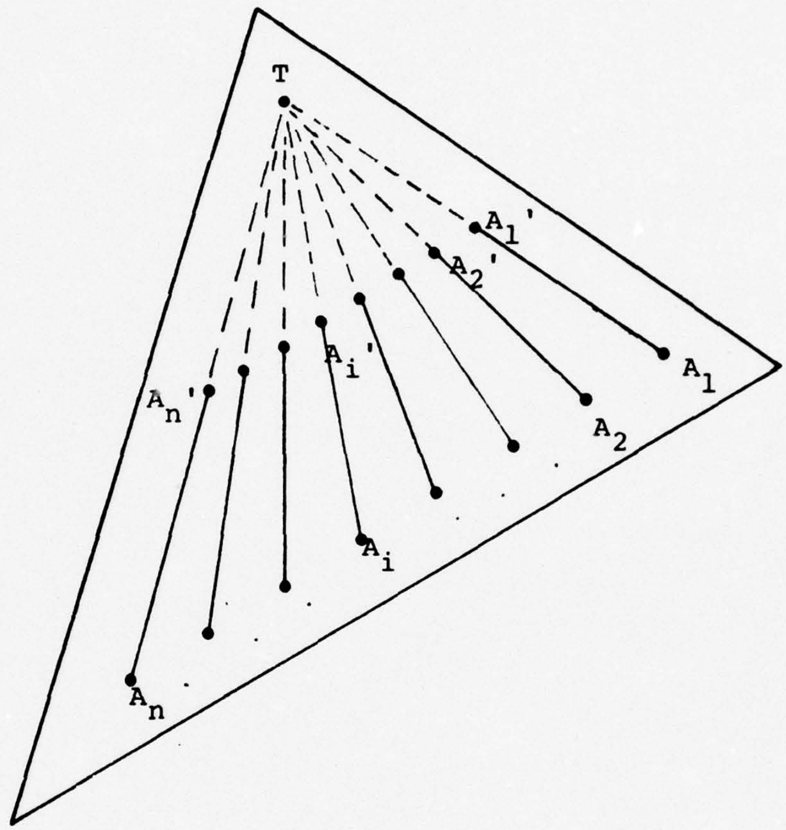


Figure 7

Projections of multiple background colors to a common T

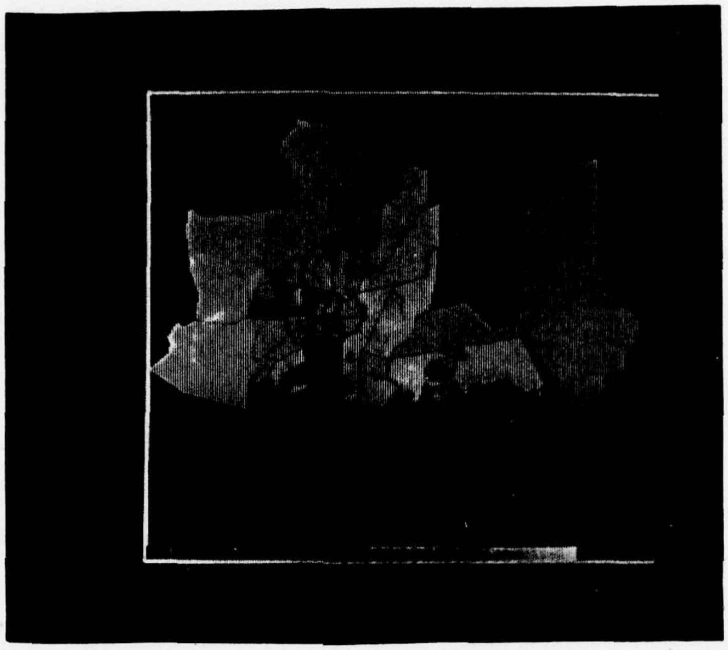


PLATE V-a.

PLATE V-b.

depicts a multiplicity of projections from A_i back to a common T. Color Plate V shows a situation involving many underlying base colors, correlating with the sorts of projections shown in Figure 7. The base colors are actually a map of New Haven, Connecticut, with different neighborhoods depicted in different shades (Plate V-a). The bottom half of Plate V, V-b, shows not only a transparent layer, but two of them, one red and one blue.

Multiple transparent layers require recursive computation to construct the necessary composite colors. For the base colors that are perceived through the first transparent layer T_1, the A_i' are calculated. When a second transparent layer T_2 is added, two situations can arise: 1) the base colors are seen directly through T_2, or, 2) the base colors are perceived through both T_1 and T_2 where T_1 and T_2 overlap. The first case is trivial, and the computations proceed as described before. For the second case, the A_i' due to T_1 are used in their turn as new "base colors". Thus, there will be A_i'' (double-prime) color patches at the intersection of T_1 and T_2 which will undergo scission to T_2 and A_i'. (Cf. Figure 8.)

Special Cases

Two special cases of color combination call for some comment. They are illustrated on color Plates VI-a and VI-b. The base figure in either Plate is a map of the city of Worcester, Massachusetts, with defined neighborhoods shown in various colors. On the upper map of Worcester, two illuminating squares are evident in the central and lower right portions of the picture. In this instance, the base

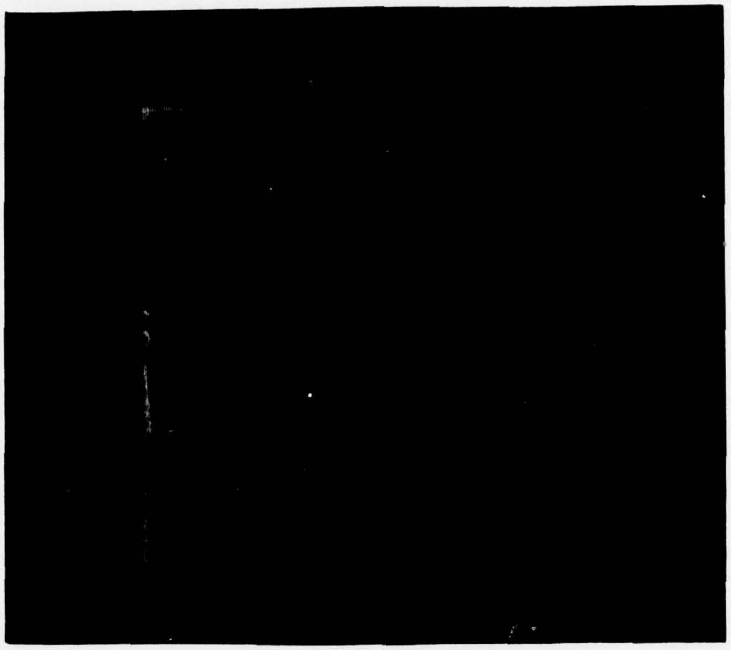


PLATE VI-a.

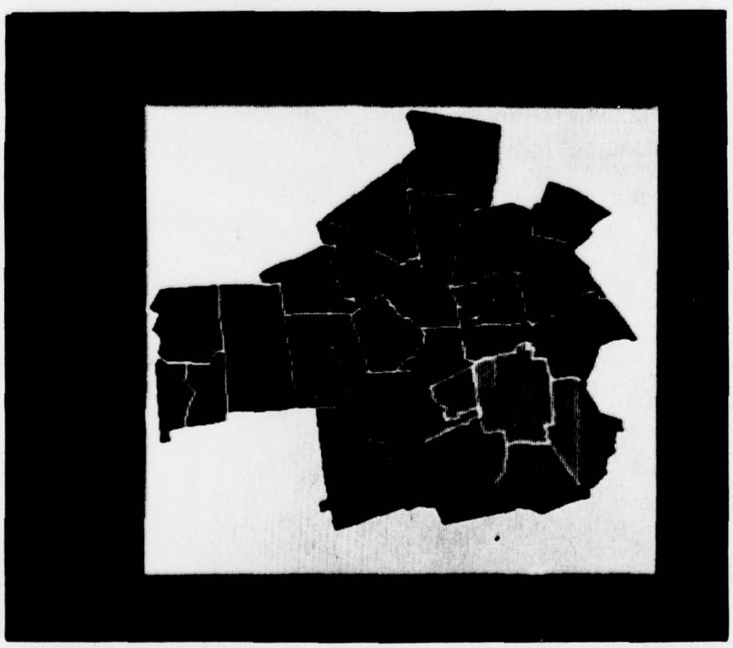


PLATE VI-b.

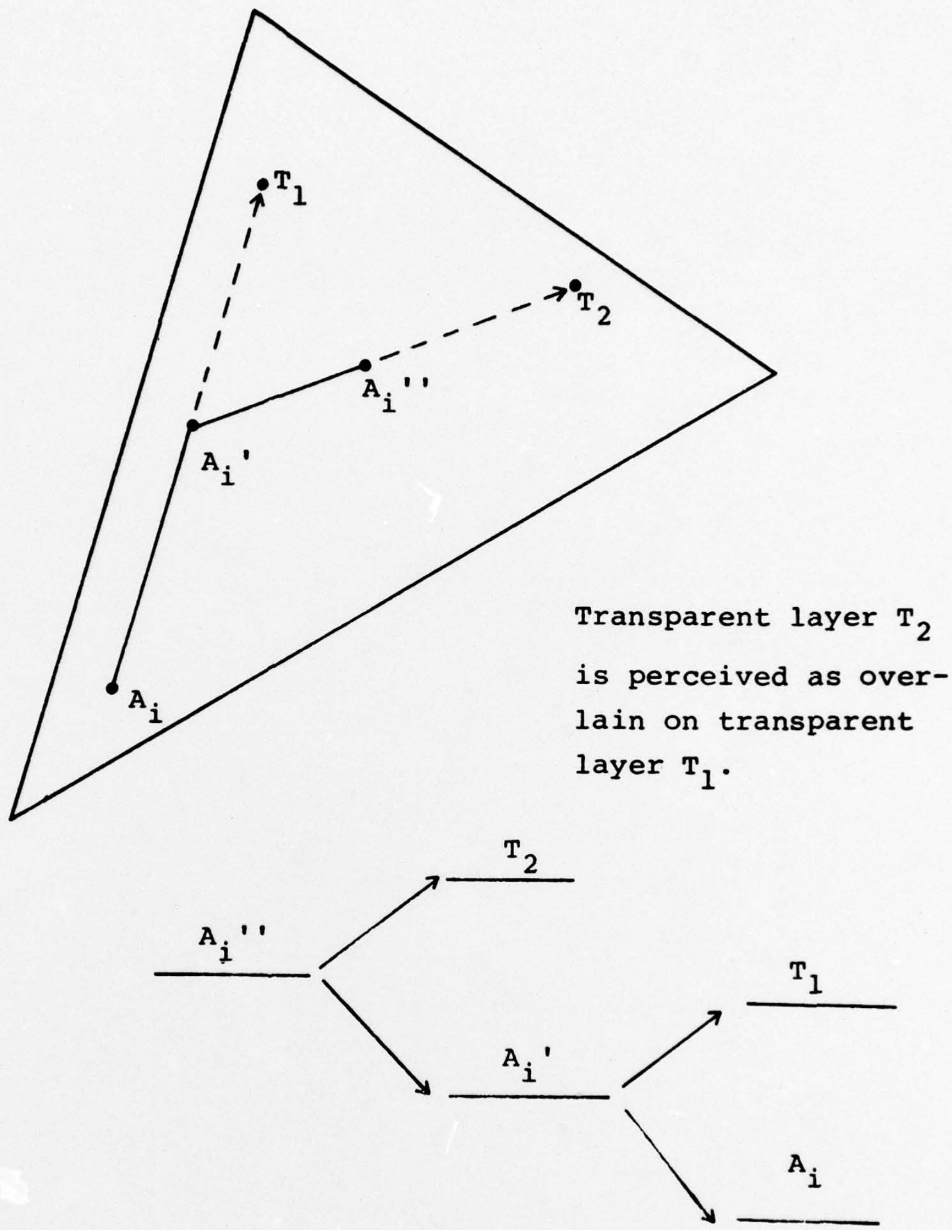


Figure 8

Schema of scissions for two transparent layers, T_1 and T_2

colors are six equi-luminant chromaticities, uniformly distributed around the neutral gray point. The A_i' and A_i'' (corresponding to the two highlighted squares) were chosen such that

$$\text{chrominance } \{A_i''\} = \text{chr. } \{A_i'\} = \text{chr. } \{A_i\}$$

$$\text{luminance } \{A_i''\} > \text{lum. } \{A_i'\} > \text{lum. } \{A_i\} \quad .$$

The perception was not one of transparency, but rather a brightness highlighting, and it can be shown that this effect is consistent with the rules of transparency construction on the chrominance projection. If, however, the luminance inequalities were reversed (not shown in the color plate), and a virtual color black (i.e., zero color weight) were utilized, then a transparency effect could be realized, the effect being essentially that of a piece of dark glass over the map of Worcester.

On the lower map of Worcester, Plate VI-b, a color saturated region and a region of greater brightness are shown as the central and lower-right squares, respectively. The base colors are less saturated than in Plate VI-a. The chrominance relationships of A_i and A_i' for this lower map are shown in Figure 9-a. Again, no common T is projected, so no transparency effect can be perceived; only a region of greater saturated colors is perceived. If, however, the primed values were less saturated, as depicted in Figure 9-b, then the virtual overlay would appear as a neutral gray

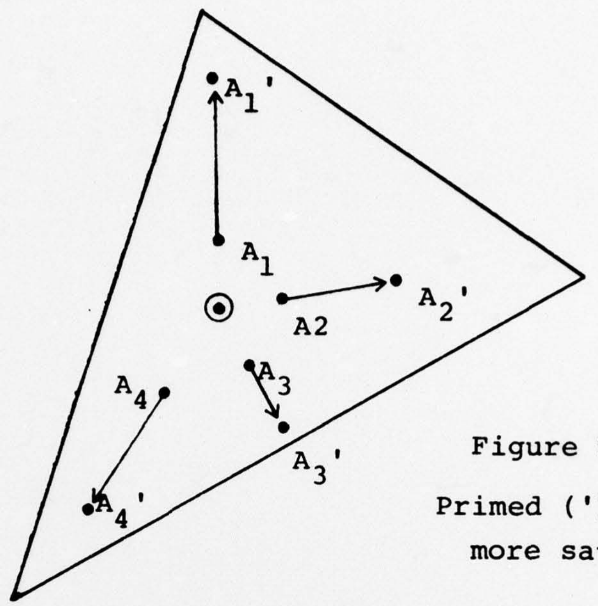


Figure 9-a

Primed (') values more saturated

⊙ = White

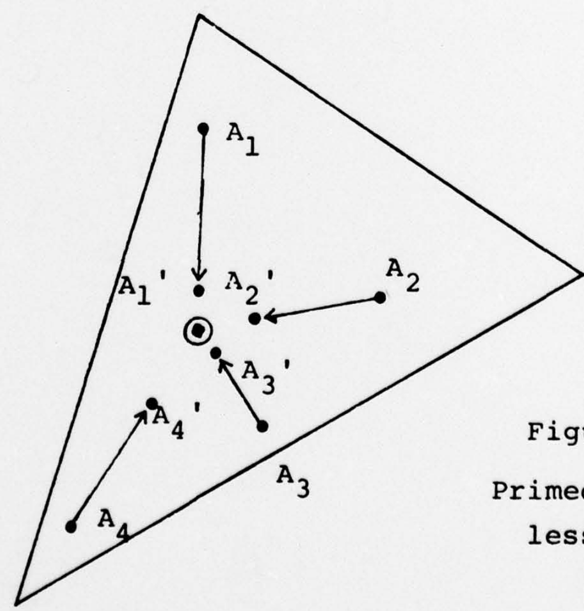


Figure 9-b

Primed values less saturated

(i.e., a "milky glass" effect). The transparency effect would fail to be fully realized unless luminance differences were also introduced into the desaturated region (this case not shown in the color Plate).

COLOR TRANSPARENCY EFFECTS
FROM MOSAICS OF OPAQUE COLOR

PART II:

An implementation on a
computer-driven color
raster-scan display

Transparency Implementation

Some discussion of our particular implementation is in order. An organization of pixel memory that facilitates a transparency scheme will be explained for a typical raster-scan display system, along the lines that our own system is organized.

A raster-scan image is comprised of an array of NxN discrete "pixels", or picture elements, whose numerical values determine the displayed pixel color. These pixel values address a color matrix, not unlike a programmable logic array (PLA). A D/A conversion is done on the output, and these analog signals control the red, green, and blue display drivers. The upper effective pixel wordlength is limited by the number of unique addresses available in the color matrix; e.g., a 512 address color matrix permits an 8-bit wordlength.

Consider a base map comprising boundary lines, alphanumerics, symbols, and colored regions. The number of different colors required to convey clearly the base information determines the preliminary pixel wordlength. Thirty-two colors necessitates allocating 5 bits per pixel. Let these 5 bits be the low order bits of each pixel and correspondingly the base colors will reside in the first 32 addresses of the color matrix. Additional bits will be appended as high-order bits.

Let us define a level of transparency as a layer exhibiting a unique virtual color and transparency coefficient (alpha). This layer need not be contiguous. For the present discussion, uniform transparency only is considered, although "unbalanced" transparency is possible. (Cf. Metelli, 1974, p. 98.) The introduction of a transparency level effectively doubles the number of perceived colors. We can achieve this effect by appending a high-order bit per pixel, and doubling the size of the actively addressed color matrix. The additional high-order bit introduces a mapping from the lower part of the color matrix onto the upper half. By calculating the upper part of the matrix as described in the section on "Color Transparency Construction", above, we achieve the desired effect. For the 32 base color case, wherever the 6th bit is a logical "1" in the picture area, the transparent layer T_1 will appear to reside over the base color area. By manipulating only the 6th pixel-bit over the image, we can alter the position of the transparent layer without affecting the underlying base map or figure.

For finite-sized color matrices, there is a trade-off between the number of base colors and the allowable levels of transparency. If b equals the number of bits/pixel for the base map (or figure), and t equals the number of transparencies, the following relation holds:

$$2^b \cdot 2^t \leq \text{number of maximum addresses in color matrix.}$$

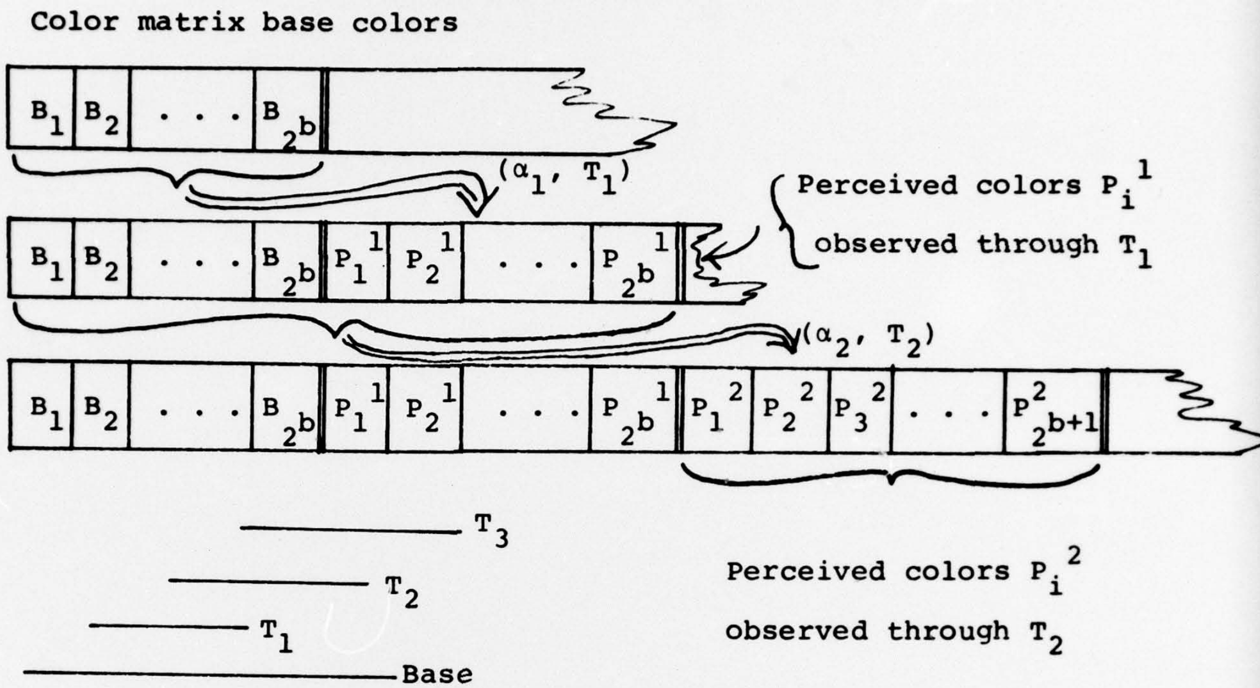
The algorithm for computing the color values beyond the base colors in the color matrix is done recursively in the following manner. The perceived colors seen through T_1

are calculated first,then the colors generated by T_2, and so forth. This procedure is depicted in Figure 10. A spatial organization of transparency levels is implicit in the algorithm. That is, T_1 is nearest to the base map, and T_j is on top of T_i where $j>i$ We can show by application of Equation (11) in Figure 10 that the perceived colors seen through T_1 and T_2 are not equal to the colors seen through first T_2 and then T_1, unless $T_1 = T_2$.

Potential Utility of the Effect

In demonstrations of the technique at the Architecture Machine Group's computer laboratory at MIT, the above approaches to creating transparency effects have been applied to multi-colored backgrounds such as complex metropolitan maps in several colors, overlain with one or more different colored transparent patches. The overlying transparent patches, of arbitrary shape and size, can also be moved freely about the map surface by the Observer using a "joystick"-type guidance device. The degree of transparency of the overlying patches can be changed dynamically. Further, it has been found possible to overlay one transparent patch with yet another transparent patch of a different color and still maintain a convincing image overall. Thus, the utility of transparent overlays in map displays lies in the emergence of powerful coding dimensions which can "highlight" a complex map background without obscuring that background.

The transparency facility is especially useful with map displays when it is desired to show symbols or icons on a map without blocking out important map detail underneath. Difficulties that can arise when opaque symbols are overlain on top of other material are illustrated by the finding that



$$P_i^k = \alpha_k \cdot C_i + (1-\alpha_k)T_k \qquad i=1,2 \ldots 2^{b+k-1},\ k=1,2 \ldots \tag{11}$$

Figure 10

Diagram depicting color matrix organization

the diagonal crossbar on prohibitive traffic signs of the symbolic or pictographic sort widely used in Europe and recently adopted in the United States tends to obscure the symbol (Dewar, 1976). Problems of a similar sort can arise with map materials as well.

Because a transparent overlay can itself be colored, several chromatically distinct overlays can serve to express logical relationships of areas in a perceptually direct fashion. The use of transparency effects in the presentation of information is an area that merits further exploration.

Yet another use of transparency that has arisen recently in our laboratory is the effect of writing with a cursor on a color display in "transparent ink". In effect, jottings, notes, figures, and so forth, can be directly set down on displayed figures as annotation without *obscuring* the underlying material.

Where the color image portrayed is that of some object rather than that of a map of a region, for example, it is possible to render selected surfaces of that object as transparent in order to show its inner construction. Making some surface of an object variably transparent (varying alpha) under Observer control makes possible "cut-away" views at will.

In these applications, as well as in other potential applications of transparency in displays, the use of the procedures described had ought to make the creation of the effects both colorimetrically sound and perceptually convincing.

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APPENDIX

Main Computer Programs

The following is a list of the main computer programs developed at the Architecture Machine Group in the course of our color research, and in particular in the course of developing the work on transparency.

MAPIN - Thematic map input program. Allows digitization of base map via the Summagraphics tablet and Imlac console. Boundaries, regional data values, and symbol locations are the information stored on disk files.

MAPDEM - Map demonstration program. Displays the digitized information of MAPIN. Allows successive yearly regional data to be scrolled on the same map.

TRANS3 - Part 1 of transparency program. Allows specification and storage of color matrices interactively by displaying the CIE chromaticity diagram and colors while displaying background colors, virtual colors, and alpha.

TRANS4 - Part 2 of transparency program. Draws a multiple square over a bipartitie field or a base map drawn by MAPDEM. By means of switches one can then manipulate: 1) the position of the transparent patch; 2) its degree of transparency; 3) its virtual color.

COLGR - General color graphics program. Plots spectral amplitudes vs wavelength and chromaticity gamuts for TV phosphers.